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A Study on CO_2 Diffusion Coefficient in n-decane Saturated Porous Media by MRI

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Abstract

The measurement of CO_2 diffusion coefficient in porous media is considered to have great significance for enhancing oil recovery rate in oil industry. In the study, MRI technology was used to observe the CO_2 diffusion process in porous media.The measurement is conducted at 24°C under four different pressures. This paper conducted in-depth analysis on the related parameters which affect the diffusion process of CO_2 in n-decanesaturated porous media. And the results showed that the diffusion coefficient increased as the pressure increased, also the diffusion coefficient was influenced by parameters including pore-throatstructure, diameter of glass sands and so on.

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Keywords: CO_2;Diffusion coefficient; N-decane; Porous media; MRI

1. Introduction

Under the pressure of the growing environmental protectionand the demand for energy conservation, it has practical significance for CO_2-EOR projects and geological storage of CO_2.The determination of the diffusion coefficient for engineering design, risk assessment and economic evaluation is necessary. During the process of CO_2 gas injection flooding, the amount of CO_2 dissolved in the crude oil relies on the molecular diffusion. Gas diffusion coefficient in the liquid saturated porous rock under reservoir conditions will affect the rate of diffusion, oil and gas miscible conditions. Pomeroy et al. [1] calculated the gas diffusion solubility and diffusion coefficient in stationary light oil. They thought that the diffusion coefficient was not directly affected by the pressure and concentration of methane under a pressure less

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than 2MPa. Grogan et al. [2] conducted CO_2 diffusion experiments in which CO_2 directly contacted with the oil and the dissolved CO_2 relied on the interface position and they calculated the diffusion coefficient of CO_2 in crude oil. Riazi et al. [3] established a semi-analytical model to measure diffusion coefficient. Furthermore, he developed a PVT (Pressure-Volume-Temperature) experimental method and in his theory the rate of pressure changed as a function of time and was considered to be affected by the diffusion process between each phase. At present, Pressure-decay method (i.e. PVT method) is widely used as it has the advantage of uncomplicated equipment and simple operation [4]. However it also has some problems such as the difficulty in ascertainingthe initial density of the gas and the system is easy to leak. Unfortunately, all of those methods cannot visulize the diffusion process. This paper presented a new method for measuring the CO_2 diffusion coefficient in oil-saturated porous media by MRI to observe the diffusion process.

2.Experimental Section

1.1. Apparatus and Materials

A simplified schematic diagram of the experimental setup is shown in Fig. 1. It mainly consists of a MRI experimental Plat form (Varian NMR Systems) with 9.4T vertical superconducting magnet field, an intermediate container, a gas cylinder, a thermostatic bath, an ISCO pump, a background pressure regulator and a data acquisition system which is used to post-process the acquired MRI images.The n-decane saturated porous media was filled into the test tube of 10 mm diameter. The porous media was packed with BZ-2 (average particle size of 2.0 mm), BZ-3 (average particle size of 3.0 mm) and BZ-4 (average particle size of 4 mm), respectively. Besides, n-decane (99.9 %) and deionized water were selected as the oil and water phase. CO_2 was injected into the intermediate container by an ISCO pump at constant pressure. The thermostatic bath was used to control the temperature of the test tube by circulating fluorescent oil. A high-accuracy data acquisition system was used to monitor the temperature and pressure of system in time during the experiment and post-process the MRI images. The dual-chamber method allows for explicit measurement of the initial gas density, many more seals are required for the equipment, and there is a greater possibility for leaks [4].

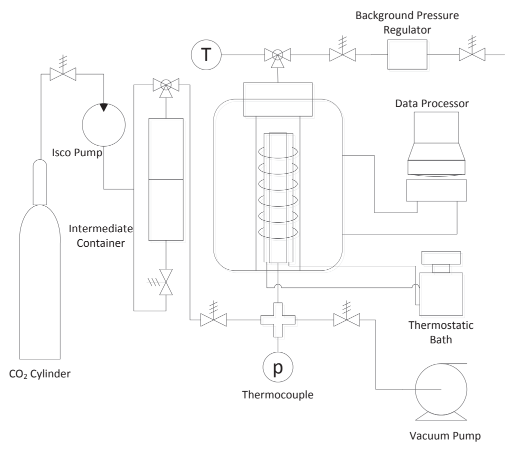

Fig. 1. The schematic diagram of dual chamber and the MRI experimental platform

1.2. Procedure

The test tube was packed with glass sands and then avacuum pump was applied for 24h. After that the porous media was saturated with n-decane.The temperature of system was kept at 24°C using the thermostatic bath. Firstly, CO_2 we used SEMS (Spin Echo Multi Slice) to acquire the image of n-decane saturated porous media. Then, CO_2 was injected into porous media from the intermediate container by the ISCO pump. The MRI data acquisition system gets the image while the pressure transmitter recorded the pressure of the whole diffusion process. The ^{1}H density changed until diffusion equilibrium and the CO_2-n-decane diffusion coefficients at different initial pressures were eventually determined by the recorded data.

3. Results and Discussion

Fig.2. (a) shows the relationship between thediffused mass and $t^{1/2}$ (square root of time) for BZ-3.By analyzing the changes in the curve, we can find a clear turning point and two approximately straight lines. In the initial stages of the experiment, theconcentration of CO_2 was high-which caused the average slope of diffusion mass and $t^{1/2}$ to increasein the initial period. Along with the increasing in quantity of CO_2 diffusedand the concentration of CO_2 became lower, the slope of the next curve decreased. Using linear fit for the second segment, we can get the relationship between concentration and $t^{1/2}$.According to Fick's second law and the continuous model, Guoet al. [5] had obtained the following equation:

$$D = \frac{k^2\pi}{4A^2F_0^2} = \frac{k^2\pi}{4(\phi A_{section})^2\tau^2F_0^2} \quad (1)$$

Where D represents the diffusion coefficient of CO_2 in porous media and F_0 represents the molecular concentration of the gas in liquid phase when the experiment began. ϕ is the porosity and τ is the tortuosity respectively.$A_{section}$ represents the contactarea between CO_2 and the pore-throat that can be acquired by calculating the rock porosity and tortuosity.k is obtained by the relation of the amount of diffused CO_2 and quadratic root of time.

Table 1.Summary of the different pressures and diffusion coefficientinporous media at 24°C

Samples	1st pressure(kPa)/ $D(10^9/m^2\cdot s^{-1})$	2ndpressure(kPa)/ $D(10^9/m^2\cdot s^{-1})$	3rd pressure(kPa)/ $D(10^9/m^2\cdot s^{-1})$	4th pressure(kPa)/ $D(10^9/m^2\cdot s^{-1})$
BZ-2	3918.34/3.56	3252.71/3.32	2812.85/3.26	2387.89/3.18
BZ-3	4249.26/3.71	2796.04/3.52	2774.01/3.34	2179.31/3.23
BZ-4	3905.81/3.69	3417.81/3.61	2932.78/3.49	2356.13/3.37

So far, we got the relationship between D and molecular concentration. MRI signal intensity is proportional to ^{1}H proton density. The concentration of the solution can be calculated by MRI image signal intensity which can be processed by Images J soft (a public domain Java image processing program inspired by NIH Image for the Macintosh) [6]. Finally, the relations between diffusion coefficient and t are depicted by means of the linear fit, when the sands were under experiment at four different pressures.Three kinds of sands were under experiments at four different pressures, see Fig.2.(b). D exhibits a slowly increasing trend with increasing pressure for the same porous media. Meanwhile D increases with the diameter of the glass sands under the same temperature and pressure. The tortuosity and pore size are different for different porous media, whichinfluenced the mass transfer process.

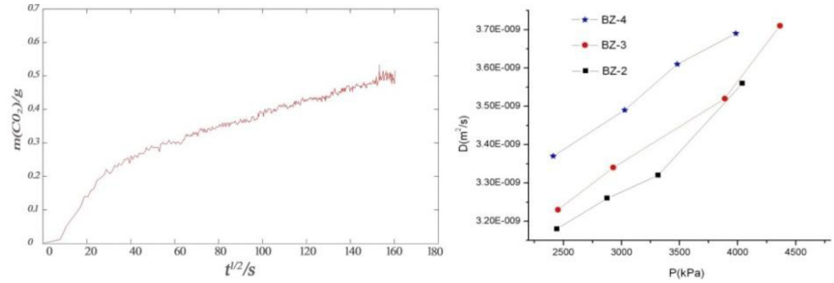

Fig. 2. (a) The relationship between diffusedCO_2 and $t^{1/2}$(BZ-3, with initial pressure of 3889kPa); (b) Diffusion coefficients of CO_2 in n-decane saturated porous media

4. Conclusions

MRI technique was used to observe the micro-scale CO_2 diffusion process in the n-decane-saturated glass beads. We studied the different pore-throat structures by changing the diameter of glass sands and the measurement was conducted at 24°C under four different pressures. The results showed that at the same temperature and in the same kind of porous media, diffusion coefficient increases with the increase of pressure. Under the same pressure, *D* increases as the diameter of glass sands increases. This work discussed the relationship of initial pressure and diffusion coefficients at the same temperature.

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Biography

Ying Teng, born in 1991, graduate student dedicated to the study of using $CO_2$to increase oil recovery rate and geological storage in Key Laboratory of Ocean Energy Utilization and Energy Conservation of Ministry of Education, school of Energy and Power Engineering, Dalian University of Technology.